Ref: U.S. Beach Erosion Board, Tech Memo 16

DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

ACCRETION OF BEACH SAND BEHIND A DETACHED BREAKWATER

TECHNICAL MEMORANDUM NO. 16

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MAY, 1950

Contribution from the Scripps Institution of Oceanography, New Series, No. 455

FOREWORD

This paper was prepared by John W. Handin of the University of California at Los Angeles and John C. Ludwick of the Scripps Institution of Oceanography. The report appeared in limited issue as Submarine Geology Report No. 8 of the Scripps Institution of Oceanography, University of California. It is believed that the results of the investigations outlined herein are of sufficient value to merit publication at this time.

The authority for publication of this report was granted by an act for the improvement and protection of beaches along the shores of the United States, Public Law No. 166, 79th Congress, approved July 31, 1945.

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ACCRETION OF BEACH SAND BEHIND A DETACHED BREAKWATER

ABSTRACT

The problem of sand transport by a longshore current is clarified by observing the effect of a breakwater on this current.

Sand samples were collected on a network from the beaches in the vicinity of the breakwater at Santa Monica, California. The distribution of median grain sizes is evidence for a reduction of the competence of the longshore current. The history of shore line changes discloses an accompanying reduction in the capacity of the current. A decrease in transporting power of the longshore current is correlated with a decrease in Q, the littoral drift factor, so that Q can probably be used as a qualitative measure of the sand transporting power of longshore currents.

The history of accretion indicates that a shore line changes position in a direction toward equilibrium with respect to the forces acting on a beach. Given enough time, it is probable that the breakwater will become connected to the mainland.

Introduction

A beach system is in equilibrium when there is a balance between sand supply and erosion such that the volumes of material entering and leaving the system are just equal. If the rate of erosion is greater than the rate of supply, a beach retrogrades, and if the rate of erosion is less than the rate of supply, a beach progrades. The detached breakwater, constructed at Santa Monica, California, in 1933-34 (figure 1), decreased erosion and caused accretion in the lee of the breakwater.

The Santa Monica Municipal Pier is located at a point on the shore between the headlands of Santa Monica Bay. Upcoast from the pier the shore line extends 3 miles to the northwest, thence more than 30 miles to the west. Downcoast from the pier the shore line extends about 15 miles in a southeasterly direction to Rocky Point (figure 2). Of rubble stone construction, the breakwater is 2,000 feet long with its southern end directly seaward of the pier. Originally the breakwater was 2,000 feet offshore and oriented parallel to the shore line (approximately northwest-southeast).

Investigations of the breakwater and adjacent beaches have been made by A. G. Johnson(5,6) of the Los Angeles City Engineer Office, and by the Los Angeles District, Corps of Engineers(2). Grant and Shepard(4) published a paper on shallow-water sediment-shifting processes which included a discussion of sedimentation behind the breakwater. J. W. Johnson(7) made a model study of accretion behind the breakwater.

FIGURE 1. AERIAL VIEW OF SANTA MONICA BAY, JUNE 22, 1947, SHOWING ACCRETION OF BEACH SAND BEHIND SANTA MONICA BREAKWATER.

(PHOTO BY FAIRCHILD AERIAL SURVEYS, INC.)

The history of accretion at Santa Monica is disclosed by successive positions of the shore line (figure 3). The purpose of this investigation is to interpret this history in terms of the physical processes which are involved, including wave erosion and transportation of sand by longshore currents. The effect of the bottom topography and the breakwater on wave diffraction and refraction is indicated by diagrams based on diffraction and refraction theory(9,12). Textural variations of the beach sands are used to test the theories.

The General Environment

The beach sand at Santa Monica is derived from the southern slopes of the central and western Santa Monica Mountains and probably in part from the beaches northwest of the mountains. The source rocks are sandstones, shales, conglomerates, and basic volcanics. Streams draining the mountains are short, intermittent, and have steep gradients. When rainfall in the mountains is of high intensity the streams become torrential. Since orientation of the shore line is such that approaching wave induce a net southerly current, sediment is moved by longshore currents downcoast to the Santa Monica beaches from the points where the streams debouch into the sea[2].

Wave trains that reach the southern California coast with sufficient energy to move sand can be classified as to source into three categories: swell from the North Pacific, arriving with deep-water heights of 3 to 6 feet and periods of 6 to 19 seconds; swell from the southern hemisphere with heights of 1 to 4 feet and periods of 15 to 20 seconds; and swell from a nearby generating area 75 to 100 miles offshore, arriving with heights of 4 feet or more and periods of 5 to 7 seconds. Less frequently, high wind waves are generated by local storms. These wind waves can approach from almost any direction between southeast and northwest and attain heights of 10 feet or more[2]. The waves which occur most frequently are so refracted that they approach approximately normal to the breakwater axis.

Sampling and Laboratory Procedure

A network of sampling points was laid out so that certain groups of points would be located over old beach zones. In order to lay out the network in this fashion the location of the old shore lines had to be ascettained from previous surveys of the Santa Monica beaches (figure 3).

At each sampling point other than on the foreshore approximately 500 grams of sand were collected from a pit about three feet deep which was dug to penetrate the upper wind-drifted sand. The samples therefore are probably more representative of the underlying old-beach material. Local sorting differences were largely eliminated by collecting intergrated samples from a 6-inch stratigraphic interval at the bottom of the pit. Samples collected from the foreshore were taken at points located midway between the edge of the water and the crest of the berm, and were collected from the surface because of the presence of very coarse sand

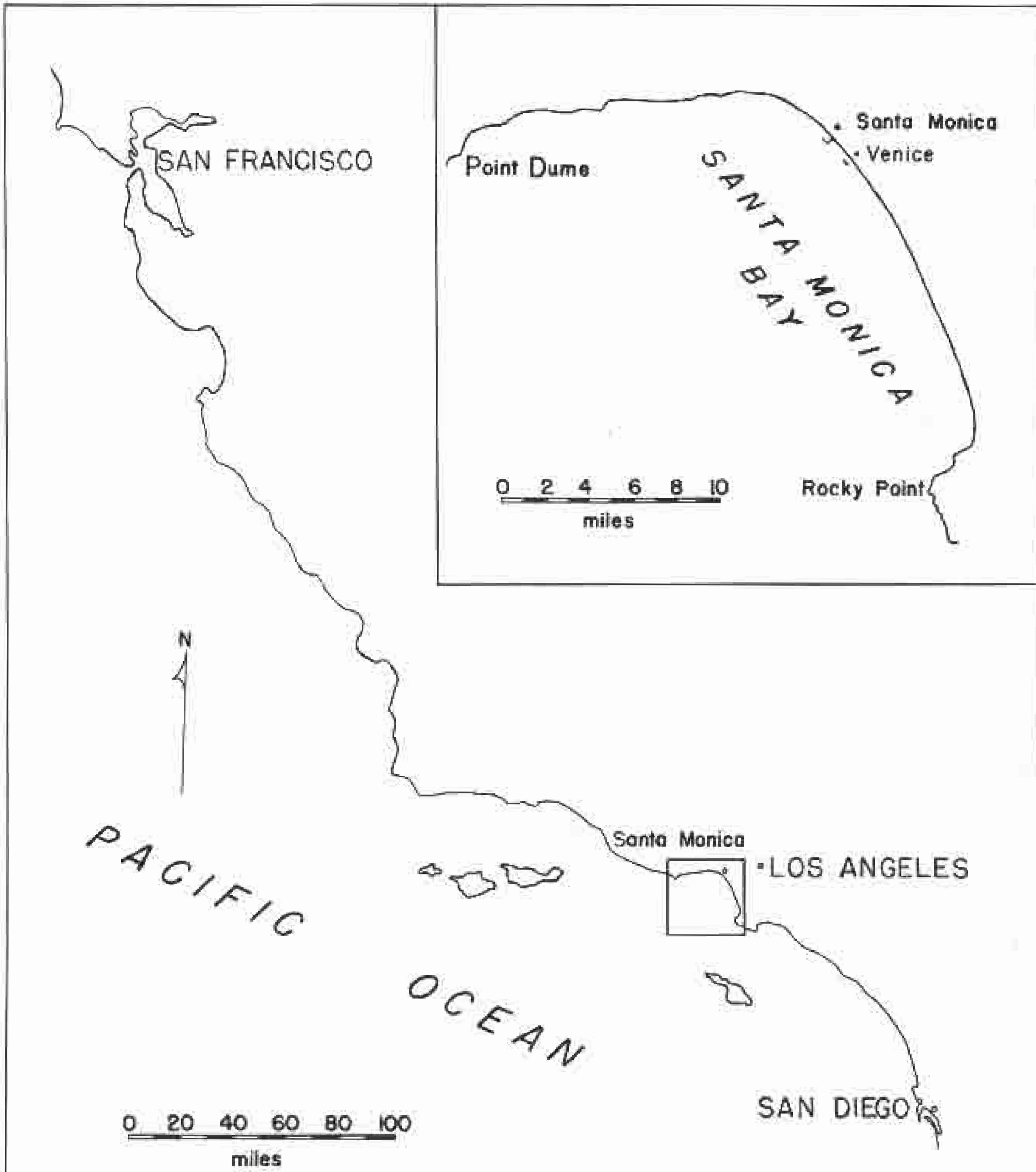

Figure 2

INDEX MAP

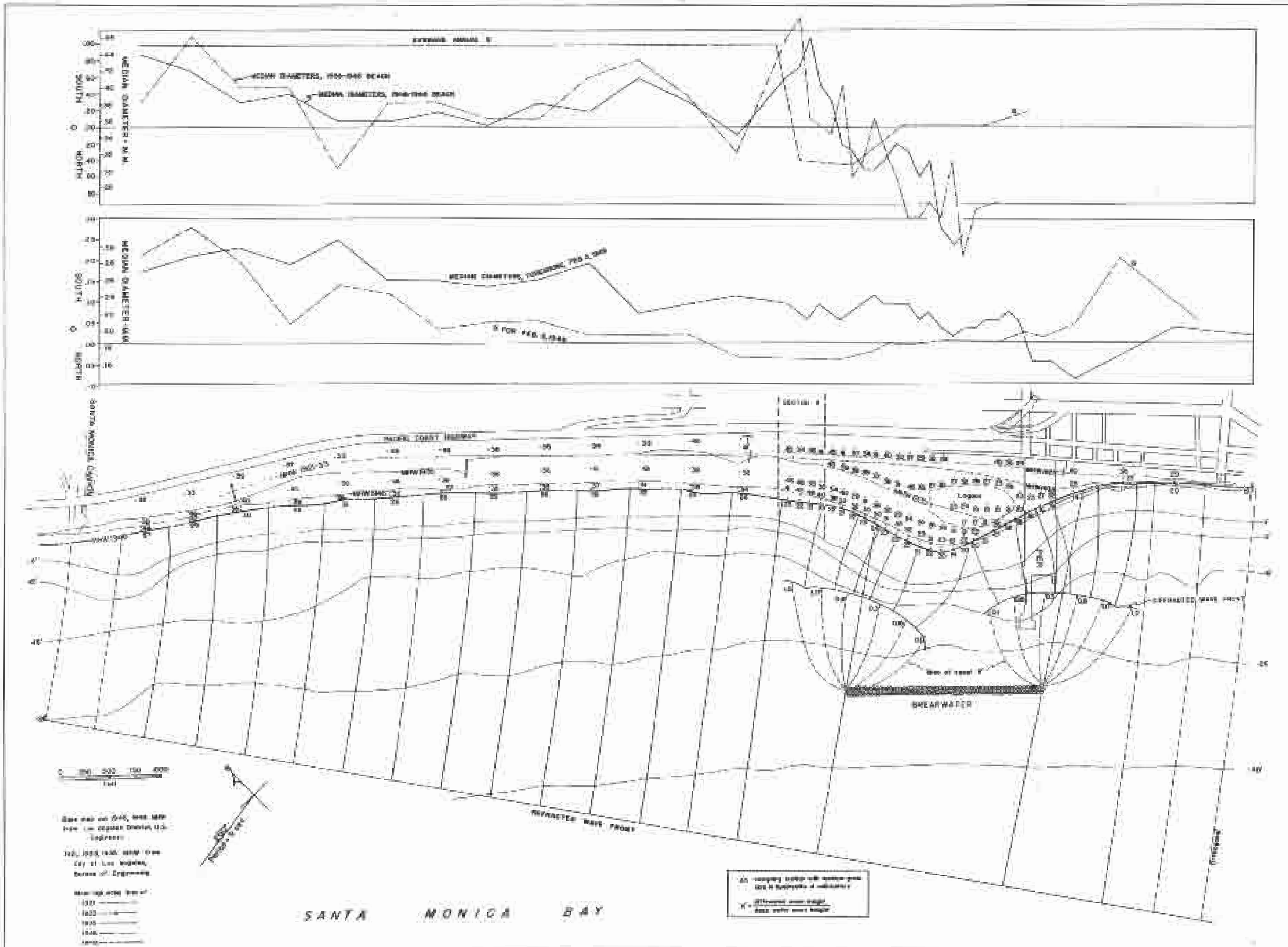
MEDIAN DIAMETER-M.M.
SOUTH
NORTH
SANTA MONICA CANYON
PACIFIC COAST HIGHWAY
Lagoon
PIER
DIFFRACTED WAVE FRONT
BREAKWATER
REFRACTED WAVE FRONT
SANTA MONICA BAY

FIGURE 3

immediately beneath the surface layer. Such samples were collected by scooping up the surface layer from an area of several square feet. This technique was employed to collect material deposited by waves occurring at the time of sampling.

Samples were sun-dried and split to three grams using a Jones sample splitter. Median diameters were determined by using an Emery settling tube[3]. This method is more rapid than seiving and probably comes closer to duplicating natural conditions of sedimentation. Values are expressed to only two significant figures because the combined experimental and "sampling" probable error is on the order of 5 per cent[8].

History of Shore Line Changes

Prior to construction of the breakwater, the Santa Monica shore line had been comparatively stable since the earliest reliable surveys[14], with the exception of a moderate advance near the Santa Monica Municipal Pier. In 1933, immediately after construction was undertaken, the shore line behind the breakwater began to advance. Successive positions of the mean high water line are shown in figure 3.

Significant facts of the shore line changes include the following:

1. The point of maximum advance of the 1935 shore line is approximately opposite the southeast end of the breakwater. There has been a progressive northward shift of the salient to the present position opposite the center of the breakwater.

2. The 1935 shore line joins the pre-breakwater shore line at a point just beyond the north end of the breakwater. Subsequently, prograding has occurred farther and farther to the north. In 1948, the beach was prograding at a point two miles north of the breakwater.

3. Between 1946 and 1948 the shore line immediately southeast of the salient receded.

During the history of accretion, the offshore contours advanced roughly parallel to the advancing shore line so that the offshore slope remained constant. There has been no appreciable change in the position of the 24-foot depth contour.

Texture of the Beach Sands

Median diameter of the sand at each sampling point is plotted in figure 3. Maximum, minimum, and average values of median grain size for each beach zone are tabulated in table 1. During 1939 and 1940, dredging on the prograded beach behind the breakwater produced a shallow lagoon. Dredgings were pumped to a point on the beach 900 feet southeast of the pier. After operations were discontinued the lagoon filled with fine sand. Median diameters of sand samples collected from the lagoon were not included in computing values in table 1.

TABLE 1

Summary of Beach Sand Grain Sizes of Samples Collected on 3 February 1949

Beach Zone	Median Diameters in mm.		
	Max.	Min.	Average
Pre-breakwater zone (pre-1933)	0.45	0.24	0.36
1933-1935 zone	.45	.23	.32
1935-1946 zone	.48	.19	North of sector A: .39 South of sector A: .29
1946-1948 zone	.46	.21	North of sector A: .37 South of sector A: .30
Foreshore Feb. 3, 1949	.31	.14	.23

Significant facts of the beach material as shown by figure 3 and table 1 include the following:

1. There is a random distribution of median diameters of the sands of the pre-breakwater beach.

2. On subsequent beaches the distribution of median diameters indicates that a variation series exists(11).

3. On the beach built between 1933 and 1935, the coarsest sand occurs at the north, and there is a decrease in grain size to the south. Finer sand occupies the site of the lagoon.

4. The samples which represent the 1935-1946 and 1946-1948 beaches show a random distribution of median diameters upcoast from Sector A (the area of maximum median grain size, arbitrarily designated Sector A for convenience in reference, see figure 3). There is an abrupt increase in grain size within Sector A, but downcoast there is a gradual decrease. To the north of Sector A, the average median grain size is greater than it is to the south.

5. On the foreshore of 3 February 1949, median diameters gradually decrease from Santa Monica Canyon to the pier.

Discussion

The Corps of Engineers has been making use of the littoral drift factor, Q, in studies of littoral transport in southern California. The Corps acknowledges that the validity of the equation relating sand transport to littoral forces has not been proved through field investigations or model studies. However, the Corps considers the analysis of Q factors, as computed by this formula, the most satisfactory theoretical approach to the correlation of littoral drift and its generating forces thus far derived. According to the Los Angeles District, Corps of Engineers[2] Q is defined as:

$$Q = k\ w\ e\ \sin 2\alpha$$

where

- Q = littoral drift factor-total amount of sand moved in littoral drift past a given point on the shore in one year by waves of a given period and direction.

- w = wave work factor, total work done by all waves of a given period and direction during an average year.

- e = relative wave energy per unit length of wave crest

$$= \frac{\text{shallow-water wave energy}}{\text{deep-water wave energy}}$$

- α = angle between a wave crest and the shore line or between an orthogonal and the normal to the shore line. The angle opens in the direction of the long-shore current.

- k = a factor depending on dimensions, and a number of unevaluated variables such as bottom slope and roughness.

Owing to the unknown magnitude of k, only relative values of Q may be computed for points on the beach. Thus for comparative purposes, k is assumed to be constant and assumed to be unity. It is assumed that wave work (energy) is the important parameter in measuring the rate of littoral drift. The deep-water wave work, w, must first be converted to wave work in the breaker zone by multiplying by the coefficient e. The longshore component of this work at a point on a wave crest is calculated by multiplying by $\sin\alpha$. It is then multiplied by $\cos\alpha$ to obtain the total longshore component of the work along the wave crest. ($\sin\alpha \cos\alpha = \frac{1}{2}\sin 2\alpha$).

Plotted on figure 3 is a combined refraction and diffraction diagram for waves prevailing at the time of sampling. The wave period and height were observed. The deep-water wave direction (260°) was assumed to be the most likely direction for waves of the observed period (9 sec.) and height (1 foot) occurring at this time of year[10]. Wave refraction methods as described by Munk and Traylor[9], and wave diffraction as developed by Putnam and Arthur[12] were utilized.

Values of Q at several points on the shore were computed using values of e and α measured from figure 3. The coefficient of energy, e, is calculated by taking the ratio of the distance separating orthogonals in shallow water to the distance separating orthogonals in deep water. The work factor, w, has been calculated for various periods and directions[13]. This factor, w, has the value 0.75 for the waves that were obtained on the day of sampling. The values of Q are plotted (figure 3) as a function of distance along the beach. An additional set of values of Q, kindly furnished by J. W. Dunham of the Los Angeles District, Corps of Engineers, is also plotted. These values are algebraic sums of Q determined for waves of all probable periods and directions of approach during an average year. Only one value of the average annual Q is available for the entire shore line between the breakwater and Santa Monica Canyon.

A comparison of the plots of median diameter of the foreshore sands and Q, shows that a decrease in Q is accompanied by a decrease in grain size. Inasmuch as Q is a function of the longshore component of the energy content of the waves, it is reasonable to suppose that competence and capacity of the longshore currents decrease with decreasing values of Q. With the progressive decrease in capacity southward there is progressively more deposition, and with the southward decrease in competence there is a progressive decrease in grain size. The finest sand on the foreshore, however, occurs at a point south of the breakwater and not at the point of minimum Q. The reason for this is that only the finest sand can be moved through the zone of minimum wave action at the salient, with the result that the source for the downcoast beaches is limited to the finest sand.

Since Q increases from the point of the salient southward, but the source of sand is insufficient to balance the increase wave erosion, the zone immediately south of the pier is one of erosion. If no sand passed the salient, the sand in this erosion zone would be coarse-grained since the finer sand would be removed first from whatever beach existed there. It seems probable that fine sand is deposited during times of low waves and the beach is eroded during times of high waves.

In Sector A there is an abrupt increase in mean grain size for the older beaches (1935-1946, 1946-1948, in figure 3) but the average annual Q shows a marked decrease. The explanation for this is believed to be that only the finer part of the sediment load can be transported through the zone of reduced wave turbulence. The coarser part is dropped resulting in an increase in median grain size. South of Sector A grain size decreases with Q and the minimum grain size corresponds to the minimum value of Q.

The average texture of the older beach sands is coarser than that of the foreshore sands, because the height of the wave prevailing at time of sampling was less than average. Handin's weekly observations over a period of one year at the mouth of Santa Monica Canyon indicate that the average annual wave height is 2.8 feet. On the day of sampling the wave height at this point was only 1 foot.

A breakwater creates what has been called a "wave shadow" (4, p.804) in its lee. Actually, approaching wave fronts are diffracted around the ends of the breakwater. The diffraction patterns in figure 3 indicate that all points on the shore receive some wave energy and that the reduction in wave energy is effective outside the limits of the breakwater. Since the refracted waves approach approximately normal to the breakwater most of the time, the point of minimum wave energy on the shore is usually opposite the center of the breakwater.

Construction of the breakwater began at the south end; accordingly the site of initial accretion was near the pier. At first, accretion resulted because of reduced wave turbulence. At some later time the configuration of the shore line was such that there was a tendency for the wave fronts to produce local reversal in the direction of the longshore current immediately north of the salient. Thereafter, the effect of the breakwater, or more directly, the effect of the projecting accretion has been essentially the same as that produced by a groin.

The effect of this tendency for a local reversal in the direction of the longshore current is to decelerate the dominently south-flowing current. However, the amount of retardation in the "zone of reversal" is not sufficient to reduce the velocity of the current to zero. Thus some fine sand is transported downcoast beyond this zone and even beyond the salient. Probably there is no "zone of reversal;" the direction of the current is determined from refraction and diffraction diagrams which indicate only theoretical values and do not necessarily represent the details of the actual current pattern. For example, no allowance is made for the existence of random eddies (rip currents) in the flow, nor is any check made in computing the longshore flow to see whether the requirements of continuity are satisfied. In the case at hand, the width of the surf zone immediately north of the "zone of reversal" is greater than the width south of it. This cross-sectional area of the currents associated with these two zones reflects the difference in width. Thus it seems probable that the larger volume of south-flowing water masks the apparent tendency for a north-flowing current which really exists only as a retarding effect.

With the completion of the breakwater, the point of maximum accretion migrated northward in response to the shift in the location of the point of minimum wave energy. As accretion progressed the projecting shore line became a more effective barrier to littoral drift and more sand was deposited on the upcoast beaches. Although the rate of advance of the shore line at the salient has decreased, the rate of total accretion has remained fairly constant. The volume of sand added each year is simply distributed over a greater distance along the shore.

Given enough time, the beaches will become stabilized along a new equilibrium alignment for the average wave conditions and the average rate of supply of detritus. At the present time, unbalanced factors in this environment continue to cause shore line changes in a direction toward the equilibrium position.

For example, the equilibrium position for the shore line of the upcoast beach is parallel to the pre-breakwater beach on a line in prolongation of the breakwater axis. Thus the upcoast beach is prograding toward this new stable shore line. If the salient ultimately reaches the breakwater, this beach will prograde rapidly and the littoral drift will bypass the breakwater and replenish the sand-starved beaches to the southeast.

By analogy to optics, a detached breakwater is probably an effective barrier to waves if it is no longer than one wave length. When the length of breakwater is only a fraction of its distance offshore, diffracted and refracted wave crests have enough distance to turn through at least one quadrant, thereby propagating wave energy sufficient to maintain sand in suspension and transit behind the breakwater. In this case equilibrium is attained before the salient reaches south of Santa Monica. At Venice, California, a shore line of equilibrium was established before the accretion reaches the breakwater. Originally this structure was about the same distance offshore as the Santa Monica Breakwater, but it is only about 600 feet long. Recently an artificial beach was built to within about 500 feet of the breakwater. Waves rapidly constructed a tombolo.

Left to itself, the Santa Monica Breakwater which was the same distance offshore but is longer than the Venice Breakwater, will probably become connected to the mainland.

Summary and Conclusions

The study of sand accretion behind the detached breakwater at Santa Monica furnished several conclusions pertinent to an understanding of littoral processes.

1. A beach system is in equilibrium when there is a balance between sand supply and erosion such that the volumes of material entering and leaving the system are just equal. If an unbalance is created by the introduction of a disturbing element into the system, ensuing changes in the system proceed toward a new equilibrium position.

2. A detached breakwater is a disturbing element if it is at least one wave length long and if it is close enough to shore to produce an appreciable reduction of wave energy in the surf zone.

3. Median grain size of the beach sand was used as an indication of longshore current competence. A correlation was found between grain size and Q, the littoral drift factor, which suggests that competence varies directly with Q.

4. The rate of accretion was used as an indication of longshore current capacity. There is a correlation between rate of accretion and Q which implies that capacity varies directly with Q.

5. The evidence from Santa Monica breakwater would seem to verify the assumption made regarding the sand transporting power of longshore currents(13), that wave energy is a more important parameter than wave height. In additional, this evidence confirms, in true scale, the results of model experiments which previously indicated a relation between sand movement and wave work(14). Finally, the evidence indicates that the littoral drift factor is probably justified as a qualitative measure of the transporting power of the littoral currents, since both competence and capacity of the longshore currents appear to vary directly with Q.

Acknowledgments

Thanks are especially due J. W. Dunham for cooperation throughout the preparation of this paper. R. S. Arthur was very helpful with problems of wave diffraction. The authors are indebted to Professor F. P. Shepard for his critical reading of the manuscript.

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